# SPECIFICATION

Electronic Version 1.2.8

Stylesheet Version 1.0

# Method and Apparatus for Heat Treating Material

## Background of Invention

[0001] This invention relates to a method and an apparatus for heat treating a material. Specifically, the present invention relates to a method and apparatus for fluid impingement quenching a forging.

[0002] Conventional quenching techniques include bath quenching and fan quenching. The bath quenching process immerses a forging within a container of oil. The oil acts as a heat sink to cool the forging. The process typically agitates the oil to increase the rate of heat transfer.

[0003] The oil bath quenching process has numerous drawbacks. The first drawback relates to the handling of the oil. Oil handling must follow specific procedures for environmental and safety concerns.

[0004] The second drawback relates to the waste stream. The used oil must enter the waste stream properly. Environmental and safety concerns demand the proper entry of the used oil into the waste stream.

[0005] The third drawback relates to predictability. Oil bath quenching is not a fully controllable process. For instance, the oil bath quenching process lacks the ability to control local heat transfer rates precisely. Generally speaking, oil bath quenching produces an arbitrary heat transfer coefficient of between approximately 70 and 140 BTU/hr $ft^2$ °F uniformly across the forging.

[0006] The final drawback relates to residual stress. Oil bath quenching tends to produce high residual stress values due to the arbitrary heat transfer coefficient. Such values can produce cracking and distortion of the forging.

[0007] The second conventional quenching technique is fan quenching. The fan quenching process uses forced convection to cool a forging. One or more fans propel air against the forging to increase the rate of heat transfer. While avoiding the environmental issues encountered with oil bath quenching, the fan quenching process does have several drawbacks. Notably, the fan quenching process may not create the heat transfer rates needed to produce the desired material properties in high temperature aerospace alloy forgings. Second, the fan quenching process also lacks the ability to control the heat transfer rates locally at various locations on the forging.

[0008] New high temperature aerospace alloys have placed greater demands on the quenching process. These new alloys require a high lower limit of the cooling rate during quenching to achieve metallurgical requirements ( *e.g.* tensile strength). As a result, fan quenching is no longer an option for these new high temperature aerospace alloys.

[0009] These new high temperature aerospace alloys also demand that the quenching process control the upper limit of the cooling rate so as to avoid the formation of cracks in the forging. As a result, oil bath quenching is no longer an option for these new high temperature aerospace alloys.

[0010] In other words, the quenching process must remain within a limited range of cooling rate values to produce the desired material qualities in the forging. Unfortunately, conventional quenching techniques do not appear to achieve these goals satisfactorily for certain applications, such as these new high temperature aerospace alloys.

## Summary of Invention

[0011] It is an object of the present invention to provide an improved quenching method and apparatus.

[0012] It is a further object of the present invention to provide a quenching technique that reduces environmental concerns.

[0013] It is a further object of the present invention to provide a quenching technique that produces less scrap during quenching caused by cracking and distortion.

[0014] It is a further object of the present invention to provide a quenching technique that produces less scrap during subsequent manufacturing operations caused by residual stress effects.

[0015] It is a further object of the present invention to provide a quenching technique that consumes less raw material.

[0016] It is a further object of the present invention to provide a quenching technique that is controllable.

[0017] It is a further object of the present invention to provide a quenching technique that can keep cooling rate values within a limited range.

[0018] These and other objects of the present invention are achieved in one aspect by a method of quenching a material, comprising the steps of: providing a material having a first section and a second section; and propelling a fluid against the first section to increase the cooling rate of the first section relative to a cooling rate of the second section.

[0019] These and other objects of the present invention are achieved in another aspect by a method of adjusting the cooling rate of a forging during quenching, comprising the steps of: providing a forging having a first section with a first cooling rate and a second section having a second cooling rate; and propelling a fluid against the first section in order to minimize a differential between the first cooling rate and the second cooling rate.

[0020] These and other objects of the present invention are achieved in another aspect by an apparatus for quenching a material, comprising: a support for receiving the material; and an outlet adjacent the support for impinging a fluid against a first section of the material, so that a cooling rate of the first section increases relative to a cooling rate of a second section of the material.

## Brief Description of Drawings

[0021] Other uses and advantages of the present invention will become apparent to those skilled in the art upon reference to the specification and the drawings, in which:

[0022] Figure 1 is an exploded, perspective view of one embodiment of the quenching apparatus of the present invention;

[0023] Figure 2 is a cross-sectional view of the quenching apparatus taken along line II-II in Figure 1;

[0024] Figure 3 is a plan view of one component of the quenching apparatus shown in Figure 1;

[0025] Figure 4 is a detailed view of a portion of the component shown in Figure 3;

[0026] Figure 5 is a cross-sectional view of the component taken along line V-V in Figure 4;

[0027] Figure 6 is an elevational view of a second component of the quenching apparatus shown in Figure 1; and

[0028] Figure 7 is an elevational view of a section of the quenching apparatus shown in Figure 1 with a forging placed therein.

## Detailed Description

[0029] Figure 1 displays an exploded perspective view of one embodiment of a quenching apparatus 100. The quenching apparatus 100 can receive an annular forging F (only partially shown in the figure), such as a turbine disk or an air seal. Although accommodating an annular shape, the apparatus could heat treat any shape of forging F.

[0030] Similarly, the apparatus 100 could quench a forging made from any material. The preferred material, however, is a high temperature aerospace alloy. Generally speaking, such material must have adequate performance characteristics, such as tensile strength, creep resistance, oxidation resistance, and corrosion resistance, at high temperatures. Course grained nickel alloys are especially prone to quench cracking due to a ductility trough at the upper temperatures ( *e.g.* 1800-2100 ° F) of the quenching process. Examples of high temperature aerospace materials include nickel alloys such as IN100, IN1100, IN718, Waspaloy and IN625.

[0031] To achieve these characteristics, the aforementioned alloys demand precise

control of the quenching process. Precise control is necessary to avoid cracking of the forging during quenching and to avoid residual stress effects during subsequent manufacturing operations on the forging. Typically, most forgings that exhibit cracks during quenching are considered scrap.

[0032] The quenching apparatus 100 preferably can provide impingement cooling to all surfaces of the forging F. The apparatus 100 includes a first cooling section 101, a second cooling section 103 and a central cooling section 105. Each section will now be described in further detail.

[0033] Figure 3 displays the first cooling section 101. The first cooling section 101 preferably corresponds to a bottom of the forging F. The first cooling section 101 includes one or more supports 107 arranged around the apparatus 100. Although the figure displays three, the present invention could use any suitable number of supports 107.

[0034] The supports 107 have recesses in which a plurality of concentric pipes 109 can reside. Although the figures show five, the present invention could utilize any number of pipes 109. The number of pipes 109 depends upon the geometry of the forging F. A larger forging F requires more pipes 109.

[0035] A plurality of spacers 111 secure to the supports 107 with conventional fasteners. The spacers 111 serve to retain the pipes 109 to the supports 107. Although the figures show each spacer 111 retaining multiple pipes 109, the spacer 111 could retain only one pipe. This would allow the individual adjustment of pipes 109 without disturbing the other pipes 109. Another important function of the spacers will be discussed below.

[0036] As seen in Figure 2, the top of the forging F could have a different shape than the bottom of the forging F. Accordingly, the second cooling section 103 may not mirror the shape of the first cooling section 101. Rather, the second cooling section 103 preferably conforms to the top of the forging F.

[0037] Similar to the first cooling section 101, the second cooling section 103 includes one or more supports 115, concentric pipes 117 and spacers 119. When fastened to the supports 115, the spacers 119 secure the pipes 117 to the supports 115. The

supports 107,115 and the spacers 111,119 could be made from any material suitable to the demands of the quenching process.

[0038] For versatility, the apparatus 100 should accommodates forgings F of various shapes. For every forging F, the cooling sections 101, 103 should generally conform to the specific shape. This could be accomplished with conventional techniques. For example, the apparatus could utilize supports 107,115 specific to each forging shape.

[0039] Alternatively, the same supports 107, 115 could be used for every forging F. To accommodate different shapes, the universal supports should include features (not shown) to allow selective positioning of each of the pipes 109, 117. In one possible arrangement, the universal supports could have height adjustable platforms upon which the pipes 109, 117 rest. The platforms could use a threaded shaft to adjust height.

[0040] In addition, either of the supports 107, 115 could be sized and shaped to allow an outermost pipe 109,117 to surround the outer diameter of the forging F. This arrangement allows the apparatus 100 to quench the outer diameter of the forging F. Not all forgings F, however, require quenching at the outer diameter. As an example, forgings F with thin sections at the outer diameter typically do not require quenching.

[0041] Figures 4 and 5 display one of the pipes 109. The pipe 109 is annular to provide axisymmetric cooling to the annular forging F. The tubes 113 can be made from any suitable material, such as tooling steel ( *e.g.* AMS5042, AMS5062, AISI4340), stainless steel (AISI310, AISI316, 17-4HP), copper and brass. As an example, the pipes 109 could have an inner diameter of between approximately 0.7" and 1.3" and have a suitable thickness. The specific values will depend upon the demands of the quenching process.

[0042] The pipes 109,117 each have an inlet (not shown) attached to a fluid source 127 using conventional techniques. The source 127 could use conventional valves (not shown) to control fluid flow to each pipe 109,117. The valves could either be manually or computer-controlled. The benefits of having such control will become clear below.

[0043] The pipes 109,117 have an arrangement of openings 131 therein. Preferably, the openings are regularly arranged around the pipes 109,117 to provide axisymmetric

cooling to the forging F. However, non-symmetric arrangements are possible. As seen in Figure 5, The openings 131 span an angle $\alpha$ of between approximately $25^\circ$ and $270^\circ$ of the circumference of the pipe 109,117. Preferably, the angle $\alpha$ is approximately $90^\circ$.

[0044] The openings 131 in the pipes 109,117 define outlet nozzles for the fluid to exit the cooling sections 101,103. The fluid propels from the openings 131 to cool the forging F. The openings 131 could have either sharp edges or smooth edges in order to provide a desired nozzle configuration. Specific geometric aspects of the openings 131 will be discussed in detail below.

[0045] Figure 6 displays the central cooling section 105. The central cooling section 105 preferably resides within the inner bore of the forging F. As with the outer diameter, the inner diameter of the forging F may not require quenching. Forgings F with thin sections at the inner diameter typically do not require quenching.

[0046] Similar to the pipes 109,117, the central cooling section 105 is a pipe that includes an inlet 133 attached to the fluid source 127 using conventional techniques. The central cooling section 105 also includes a plurality of openings 135 at an outlet end. The size and shape of the central cooling section 105 depends upon the geometry of the forging F.

[0047] Assembly of the apparatus 100 proceeds as follows. The assembled first cooling section 101 receives the forging F. Specifically, the forging F rests on the spacers 111. Then, the second cooling section 103 is placed over the forging F. Likewise, the spacers 111 rest on the forging F. Next, the central cooling section 105 is placed inside the central bore of the annular forging F. The central cooling section 105 preferably rests on the supports 107 of the first cooling section 101, and is spaced from the forging F by abutting the distal ends of the spacers 111. Other arrangements, however, are possible. The apparatus 100 is now ready to begin the quenching operation.

[0048]

The apparatus could utilize any suitable fluid, such as a gas, to quench the F. Preferably, the present invention uses air. The source 127 could have a diameter of between approximately 2.5" and 3.5". The source 127 could also supply

approximately 12 lb/sec of ambient ( *e.g.* 65–95 °F) air to the apparatus 100 at a pressure of between approximately 45 and 75 psig. Again, the specific values will depend upon the demands of the quenching process.

[0049] Generally speaking, one goal of the present invention is to control the cooling rate of the forging F precisely. This precise control allows the use of impingement cooling on the forging F. Impingement cooling is a subset of forced convection cooling that produces significantly higher heat transfer coefficients than the remainder of the forced convection regime. For example, conventional forced air convection can achieve heat transfer coefficients of approximately 50 BTU/hr ft$^2$ °F with typical equipment. Impingement cooling, on the other hand, can achieve heat transfer coefficients up to approximately 300 BTU/hr ft$^2$ °F.

[0050] Figure 7 provides the spatial relationship between the pipes 109,117 and the forging F. Although displaying the first and second cooling sections 101,103, the spatial relationships shown in this figure are also applicable to the central cooling section 105. As seen in the figure, the spacers 111 provide a gap between the forging F and the pipes 109,117.

[0051] The openings 131 in the pipe preferably have a diameter d adequate to propel a sufficient amount of fluid against the forging F to perform the quenching process. As an example, the diameter d of the openings 131 could be between approximately 0.55" and 0.75". At this diameter d, preferably between approximately 0.002 lb/sec and 0.01 lb/sec of fluid flows through each opening 131 at a velocity of between approximately 200 ft/sec and 1000 ft/sec.

[0052] The gaps formed between the pipes 109,117 and the forging F created by the spacers 111 are an essential aspect of the present invention. The spacers 111 define a distance Z between the pipes 109,117 and the forging F. The distance to diameter ratio (Z/d) should range between approximately 1.0 and 6.0.

[0053]

A circumferential spacing X exists between adjacent openings 131 in the pipes 109,117. The circumferential spacing of the openings 131 ensures adequate fluid flow to the forging F to achieve the desired cooling rate. The circumferential arrangement of the apertures 131 also ensures axisymmetric cooling of the forging F. The

circumferential spacing to diameter ratio (X/d) should be between approximately 0.0 and 24.0.

[0054] Finally, a radial spacing Y exists between adjacent openings 131 in the pipes 109. Similarly, the radial spacing of the openings 131 ensures adequate fluid flow to the forging F to achieve the desired cooling rate. The radial spacing to diameter ratio (Y/d) should be between approximately 0.0 and 26.0.

[0055] Using these parameters, the present invention can treat all sections of the forging using impingement cooling. Impingement cooling is preferred because of the combined effect of increased turbulence and increased jet arrival velocity significantly increases the heat transfer coefficient of the apparatus 100.

[0056] By varying the aforementioned parameters within the suitable ranges, the present invention can achieve another goal of the present invention - to reduce any differential between the cooling rates of different areas of the forging F. Ideally, the present invention seeks to equalize the cooling rates across all areas of the forging.

[0057] The present invention reduces temperature gradients within the forging F by providing more impingement cooling to one area of the forging F compared to another area of the forging F. In terms of heat transfer, the volume of an object equates to thermal mass and the surface area of the object equates to cooling capacity. Objects exhibiting a low surface area to volume ratio cannot transfer heat as readily as objects with higher surface area to volume ratios.

[0058] The present invention seeks to increase the heat transfer of areas of the forging F that exhibit low surface area to volume ratios. Practically speaking, the present invention provides more cooling to surfaces of the forging F located adjacent larger volumetric sections than surfaces of the forging F located adjacent smaller volumetric sections.

[0059] The present invention can locally adjust impingement cooling by varying any of the aforementioned characteristics. For example, one can selectively adjust cooling to desired areas of the forging F by adjusting the diameters of the pipes 109,117, by adjusting the diameter of the openings 131, by adjusting the size of the spacer 111 or by adjusting the density of the openings 131 ( *i.e.* adjust spacing distances X or Y)

during the system design stage. During operation of the apparatus 100, one can selectively adjust the cooling to desired areas of the forging F by adjusting pressure in each pipe 109,111,133. The aforementioned valves on the supply 127 could be used to adjust pressure. Any other technique to adjust pressure could also be used.

[0060] The present invention could leave these characteristics static during the quenching process. In other words, the apparatus 100 could keep the selected pressures in the pipes 109,111,133 constant throughout the entire temperature range of the quenching process. Alternatively, the present invention could dynamically adjust the pressures in the pipes 109,111,133 during the quenching process. For example, the apparatus 100 could operate at a desired pressure until the course grain nickel alloy forging F exits the temperature range of the ductility trough ( *e.g.* 1800-2100 ° F). Thereafter, the apparatus could operate at a reduced pressure for the remainder of the quenching process. Other variations are also possible.

[0061] The present invention can produce heat transfer coefficients greater than those created by oil bath quenching ( *e.g.* 70-140 BTU/hr ft $^2$ ° F) or fan quenching ( *e.g.* 50 BTU/hr ft $^2$ ° F). The present invention can produce a heat transfer coefficient of approximately 300 BTU/hr ft $^2$ ° F.

[0062] Despite the higher heat transfer coefficient, the quenched products that the present invention produces exhibit lower residual stress values than those products created by oil bath quenching. The arbitrary cooling rate of oil bath quenching produces high residual stress values. The present invention, on the other hand, achieves lower residual stress values because of the ability to differentially cool the forging F ( *i.e.* control the temperature gradients across the forging). Note that reference to the residual stress values produced by fan quenching is not appropriate because fan quenching cannot meet the cooling requirements needed to quench high temperature aerospace alloys.

[0063] The present invention has been described in connection with the preferred embodiments of the various figures. It is to be understood that other similar embodiments may be used or modifications and additions may be made to the described embodiment for performing the same function of the present invention without deviating therefrom. Therefore, the present invention should not be limited to

any single embodiment, but rather construed in breadth and scope in accordance with the recitation of the appended claims.